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TOWARDS NEW FUNDAMENTALS

H. JACK RUITENBEEK

Canadian Environmental Advisory Council

INDICATORS OF ECOLOGICALLY SUSTAINABLE DEVELOPMENT

Canadian

Environmental

Advisory

Council

Indicators of Ecologically Sustainable Development: Towards New Fundamentals

H. Jack Ruitenbeek

November 1991

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The Canadian Environmental Advisory Council

The Canadian Environmental Advisory Council (CEAC) is a body representing a cross-section of Canadians who are knowledgeable and concerned about the environment. It operates in a confidential advisory capacity to the Minister of the Environment. It provides the Minister with an alternative to the advice provided by the Department of the Environment and other federal agencies, and to the advice of specific interest groups. CEAC's public role, in terms of activities such as the publishing of reports, is therefore secondary to its primary function of advising the Minister of the Environment.

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Canadian Environmental Advisory Council
Conseil consultatif canadien de l'environnement

November 14, 1991

The Honourable Jean Charest
Minister of the Environment
Ottawa (Canada)
K1A 0H3

Dear Mr. Charest:

I am pleased to submit the third in a series of three reports by the Canadian Environmental Advisory Council on the subject of Indicators of Ecologically Sustainable Development. The report describes what are called "five new fundamentals" that should be reflected in the next generation of decision support indicators. The fundamentals are intended to be used to build upon existing approaches to reporting environmental information in a way which will increase the relevance of such information to senior decision-makers.

The Council's work on indicators has extended over a period of almost two years. It is clear from our investigations that designing indicators of ecologically sustainable development is a very challenging task, and it will take many years of concerted effort to develop a full set of policy-relevant indicators. Nevertheless, this is a very important task and we encourage you to continue to support and lead the work that is being done within Canada and internationally.

Please accept our best regards and our commitment to further service on your behalf.

Sincerely,

Robert Page
Chairman

Canada

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Acknowledgments

The writing of this paper has a rather unusual history. The first version consisted only of an abstract stating the "five fundamentals". The second version consisted of a "summary paper" that provided some elaboration of each of the fundamentals. This second version was subsequently expanded to provide more details on the derivation of the fundamentals, as well as examples of how they might be applied. Each of the versions came under substantial scrutiny, and the author is indebted to those who provided input and comments.

In particular, the author thanks Shirley Conover, Joseph Potvin, Ken Ogilvie, Tony Friend, Susan Holtz, and Stan Rowe, all of whom made substantial comments on the earlier versions. The reader is reminded, however, that any opinions and conclusions expressed herein are the responsibility of the author, who also takes full responsibility for any errors of commission or omission.

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Preface

The Canadian Environmental Advisory Council (CEAC) began work on the subject of sustainable development indicators following the July 1989 meeting of leaders of the G7 summit nations. At this meeting, Prime Minister Brian Mulroney proposed that indicators should be prepared that link economics and the environment, and assess the compatibility of economic development and the protection of the environment, leading to sustainable development. The proposal was endorsed, and a recommendation was made that the Organization for Economic Cooperation and Development examine how selected environmental indicators could be developed, in the context of its work on integrating environmental and economic decision-making.

During the second half of 1989 and early 1990, CEAC reviewed studies and literature on economic and environmental indicators. Two important conclusions were reached. First, the most immediate target audience was identified as the senior policy-makers and economic analysts playing key roles in government, corporate, and development agency planning and decision-making processes. Second, since this target group relies heavily on economic analysis and resulting indicators, CEAC needed to examine how economic analysis systems could be broadened to incorporate sustaining environmental resources and life-support systems. CEAC's premise was that these indicators would be used in policy- and decision-making at the highest levels of government and industry.

Since both economics and sustaining the environment were involved, the search for indicators generated discussions with leading economists and ecologists in Canada. In addition, CEAC met with staff at the United Nations and the World Bank. These investigations led CEAC to the conclusion that the development and effective use of indicators depend largely on the economic, ecological, and political paradigms subscribed to by decision-makers. Integrating economic and environmental decision-making is complicated not only by incomplete knowledge and information, but also by different theories and assumptions of economics and ecology, as well as constraints imposed by decision-making processes.

To examine the complex issues relevant to indicators of sustainable development, CEAC decided to host a two-day workshop. CEAC invited leading representatives of various schools of thought in economics and ecology together with senior Canadian policy- and decision-makers to explore the question: **How do the conceptual foundations of economics and ecological analysis shape the indicators that will motivate policy in the 1990s?**

To stimulate discussions at the workshop, three delineation studies were commissioned. The first two describe the major alternative schools of thought in economics and ecology, and comment on how these schools propose to deal with the new sustainable development policy agenda through concepts such as 'natural capital' and 'ecological integrity'. The authors outline some of the implications for preparing indicators of ecologically sustainable development. The third study examines decision-making processes and the further complications that they introduce into the design and choice of indicators. This third study also contains an appendix that evaluates several economic analysis systems for their ability to incorporate environmental factors.

In July, 1990, close to 40 experts and senior decision-makers assembled at a workshop hosted by CEAC in Ottawa. Conceptual debates centred around the three delineation studies, while more practical discussions were held on taxation, measurement, and investment. Following these discussions, the participants identified five areas of particular significance and focused discussions were held on: regenerative capacity; pricing and taxation; ethics; worst-case scenarios; and natural capital.

The July workshop was an intellectually rigorous event that stretched the parameters and perspectives on sustainable development to their limits. The discussions were recorded in an extensive set of workshop proceedings prepared for the participants. In addition, CEAC decided to publish three documents under the general title of *Indicators of Ecologically Sustainable Development*:

1. Economic, Ecological, and Decision Theories
2. Synthesized Workshop Proceedings
3. Towards New Fundamentals

The first document contains the three delineation studies prepared as background papers for the workshop. The second document synthesizes the workshop proceedings, bringing

together the array of ideas and insights contributed by the participants. The third document is a distillation of the findings and sense of the workshop, as well as the work done by CEAC since July 1989 on indicators of ecologically sustainable development. It identifies five new fundamentals that should be reflected in the next generation of decision-support indicators. These fundamental principles significantly extend existing approaches to reporting environmental information, and they form part of the longer-term agenda for developing policy-relevant and operationally useful indicators.

CEAC's role in developing these indicators is first and foremost to advise the Canadian federal Minister of the Environment on the appropriate scope and direction of work in this area. While avoiding duplicating work on indicators being done by other groups, CEAC has benefited from the generous sharing of information by Environment Canada, Statistics Canada, and the National Round Table on the Environment and the Economy. The Council is not mandated to conduct ongoing research on a given subject. Hence, the three documents published represent a conceptual and, we hope, pragmatic contribution to the work being done by Canada and other nations on finding ways to integrate economic and environmental policy- and decision-making.

Author's Foreword

The Canadian Environmental Advisory Council (CEAC) has over the past year been responding to both international and domestic needs to develop indicators which link environment, economics and social equity to serve the purposes of a wide spectrum of decision-makers. Through looking at ecological issues, economic issues, and issues in decision-making itself, this paper identifies five new fundamentals which should be reflected in the next generation of decision support indicators. Indicators should:

a) reflect a ***broader scope*** — the economy and human behaviour within it should be acknowledged as a subset of the broader ecosystem which supports them;

b) reflect ***distributive elements*** which are important from a social equity viewpoint — incidence of both the costs and benefits of environmental degradation on various income and interest groups, for example, should be explicit;

c) have applications as a forward-looking ***projective tool*** rather than just a descriptive tool for monitoring current or past conditions;

d) reflect ***explicit linkages*** between human economic behaviour and the degree of vigour and productivity of the broader ecosystem; and,

e) recognize the ***inherent uncertainty*** in ecosystem behaviour and responses.

All of these fundamental principles represent significant extensions to existing approaches to reporting environmental information. Environmental indicators such as those included in the Environment Canada report provide a good base which, augmented by additional analyses, transforms them into indicators which do reflect the principles of sustainable development. One such augmentation might include, for example, an indicator which shows average water quality available to the poorest segments of a country's population.

In some cases, additional research and improvements to the current state of ecosystem science are required to generate such information. However, much of this information can be presented using currently available analytical techniques. A number of the tools of applied economics, for example, are well-suited to analysing problems dealing with distributive questions, behavioural projections, and uncertainty. The current challenge is in receiving more widespread political endorsement of the principles enumerated in this paper.

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1 Introduction

Background and Purpose of Paper

Over the past year, the Canadian Environmental Advisory Council (CEAC) has been responding to both international and domestic needs to develop indicators to assist decision-makers in working towards a society that embodies the principles of sustainable development. The need for such indicators was identified — among other initiatives — during the 1989 G7 summit, and Canada has continued to maintain a leading role in addressing this challenge.

In addition to recognizing the practical applications for which indicators of ecologically sustainable development (ESD) will be designed, CEAC has addressed the theoretical underpinnings of the economic, ecological, and analytical systems which might define ESD indicators. A number of independently authored papers were contracted by CEAC to survey approaches to some key issues in these areas. These, in association with other relevant background materials developed outside of CEAC, were used as a starting point for extensive discussions between economists, ecologists, and decision-makers in a participatory workshop held during the summer of 1990.

Ensuing discussions and documentation have provided a rich array of practical insights which are useful for defining and designing practical indicators and techniques for their interpretation. The workshop proceedings and its background papers provide an important objective record reflecting a wide diversity of well-informed opinion and experience.[1] The background papers surveyed issues relating to economic theories of resources and environment, ecological theories of ecological integrity, and decision theory, and described how different theoretical paradigms could lead to different approaches to designing indicators. While drawing material from and discussing these background papers, the workshop also explored the use of ESD indicators in selected applications in: (i) project appraisal for the financing of conservation investment, (ii) resource and environment provisions in taxation, and (iii) resource and environment adjustments in economic accounting. Intensive discussions of five core issues — regenerative capacity, ethics, pricing, natural capital, and worst-case scenarios — were also held during the workshop.

As the workshop was designed to explore and understand the differences among various schools of economic and ecological thought, a consensus was neither sought nor reached regarding the many individual technical issues. But some clear messages relating to the *principles* of indicator design did emerge as a result of the discussion. The purpose of this paper, therefore, is to describe these principles and how they emerged from the various individual key technical issues. Not all of the issues raised at the workshop are discussed in this paper; the specific issues dealt with are intended to provide a representative selection of those which clearly contribute to the principles.

While this paper is based on a synthesis and analysis of all of the material available to CEAC, it contributes to a broader context of international efforts to design meaningful ESD indicators. In particular, the principles can form a basis for augmenting environmental indicators such as those included in the Environment Canada report.

Key Issues and their Linkages

As illustrated in Figure 1, key technical issues were generally discussed from four different angles during the workshop. First, technical issues dealing with indicator *demand* broadly looked at the manner in which ESD indicators are used by different decision-makers. Second, issues reflecting indicator *supply* looked more closely at the practical constraints and theoretical premises for designing indicators: a key premise of this work is that different economic, ecological and political paradigms will generally generate different conclusions of what appropriate specific ESD indicators are. Third, various *analytical techniques* were addressed to assess whether different techniques have different information requirements, and to identify those techniques which might be most appropriate for making the technical possibilities of indicator "supply" somehow meet the actual "demand" for indicators. Finally, to underline the linkages

[1] The background papers are published in CEAC (1991), *Economic, Ecological, and Decision Theories: Indicators of Ecologically Sustainable Development*, CEAC: Ottawa. A synthesis of the workshop material is provided in Potvin, J.R. (1991), *Indicators of Ecologically Sustainable Development: Synthesized Workshop Proceedings*, CEAC: Ottawa.

Figure 1.
KEY ISSUES IN ESD INDICATOR DESIGN

Indicator "Demand" Issues
How are indicators used?
Who uses indicators?
How much information is required?

Indicator "Supply" Issues
How is social equity captured?
How is ecological sustainability captured?
How is economic sustainability captured?
How are the linkages reflected?

Tools of the Trade
Are our analytical techniques adequate?
Can we reflect risk and uncertainty?

Indicators in Policy Design
What is the most critical policy focus?

between these issues and their ultimate applicability to policy decisions, some discussion was held relating to what the most critical *policy focus* should be in designing ESD indicators.

Five New Fundamentals

The specific technical issues are generally open to wide interpretation and a plurality of views. All of these views have, to varying degrees, sound justifications; yet divergence of opinion is not uncommon. Hence, at times there is little basis for agreeing that some types of information are better than others in capturing the essence of sustainable development. Some important lessons nonetheless arise from this divergence of opinion: lessons which have important implications for the broad approach to designing ESD indicators, even though they provide no explicit judgment on which underlying economic or ecological theory is most appropriate. These lessons are embodied in five "new fundamentals" for ESD indicator design, as summarized in Figure 2.

It is important to realize that these "new" fundamentals are not intended to replace any existing principles of ESD indicator design; there are, by and large, no existing principles to replace. The new fundamentals do, however, demand an augmentation to many of the current initiatives which are being undertaken to design indicators. In short, these fundamentals will generate a richer information set for decision-makers.

Overview of Paper Contents

This paper commences with a broad look at the principles of the "new fundamentals", focusing on some of their key elements and how they are relevant in a policy context. It then discusses how each of the main technical issues contributes to the conclusion that these principles are important and independent of the technical disagreement which can and does arise in specific indicator design. Next, the discussion examines these fundamentals in the context of some specific example indicators. From this, the paper concludes with a description of the next steps which might be taken in applying these fundamentals.

It should be noted that, throughout this paper, example indicators are sometimes provided to illustrate particular concepts. The specific indicators used, however, should be regarded as illustrative only; their use as an example does not represent an endorsement or suggestion that these specific indicators are the most appropriate from either a scientific or an economic perspective. The specific examples primarily illustrate how an existing indicator can be extended into *one potential set* of indicators which more completely reflects the five fundamentals. More research, in many cases, will be necessary to determine the *most appropriate set* of indicators.

Figure 2.

FIVE NEW FUNDAMENTALS FOR ESD INDICATOR DESIGN

A *Broader Scope*
ESD indicator design must acknowledge that the economy and human behaviour are part of a broader ecosystem which supports them.

***Distributive* Elements**
Social equity — in terms of the incidence of costs and benefits — must be an explicit component of ESD indicators.

***Projective* Applications**
ESD indicators must be useful for forward-looking applications and not just descriptive of past or current conditions.

Explicit *Linkages*
Drawing connections between human economic behaviour and broader ecosystem health is a vital function of ESD indicators.

Inherent *Uncertainty*
Unquantifiable uncertainty in ecosystem behaviour and response requires that ESD indicators must explicitly communicate such uncertainty to decision-makers.

It is significant that two complementary perspectives seem to be implicit in developing the five fundamentals discussed in this paper. First, they are a manifestation of what can best be described as a more *global outlook* to achieving sustainable development. Holistic approaches to policy identification and decision-making — those which recognize the interdependence among different components of global systems — are becoming increasingly important and underlie the derivation of these fundamentals.

Second, and of key relevance to what is often a very technical area, the five fundamentals recognize that we are ultimately trying to provide *information* for ecologically sustainable development. Although the term "ESD indicator" is still used in this paper, the time is perhaps approaching when we will be better off to dispense with the sometimes restrictive connotations of the term "indicator" and replace it with the more appropriate term: "information".

2 A First Look at the Fundamentals

Introduction

By concentrating on fundamental principles of indicator design rather than on specific indicators, it is intended that all indicator design efforts — irrespective of their theoretical basis — be directed towards capturing these principles. Substantial effort is being put towards indicator design in many disciplines; it will largely be incumbent on each discipline, and on each individual working in the field of indicator design, to reflect on how these fundamentals can best be applied within their particular areas.

Before showing how the five fundamentals are derived, it is appropriate to look at each one briefly: (i) to illustrate their policy relevance; and, (ii) to expand on some issues of definition which cut across all of the fundamentals. This will also allow the reader to see how the fundamentals arise as the different technical issues are discussed in subsequent chapters. Although some policy issues are addressed here, the policy framework will be revisited in greater detail in Chapter 6.

Answering the Key Policy Questions

From a policy perspective, the five key fundamentals are particularly relevant as policy-makers are currently faced with heightened demands to implement policies that are consistent with principles of ecologically sustainable development. When applied to indicator design, as shown in Figure 3, the five fundamentals are a natural extension of traditional approaches to typical questions of importance to those concerned with public policy formulation.

Fundamental 1: A Broader Scope

The first policy issue, that of *where* society and humankind stands in relation to the broader global ecosphere, has traditionally been largely ignored: policies focused on ensuring that humanity's immediate needs were met. It is increasingly obvious, as the availability of natural resources and environmental functions often constrains what can be done, that human behaviour is part of a broader ecosystem which supports humanity's needs. Indicators which are to be useful must therefore reflect this *broader scope*. A key corollary to this is that we acknowledge that humanity's long-term needs require the existence of healthy ecosystems, and that we start paying explicit attention to the well-being of these ecosystems.

Fundamental 2: Distributive Elements

The second policy issue, that of *who* is affected by conditions such as environmental degradation, has also traditionally not been addressed to the required degree of detail. Environmental degradation is typically reported in aggregates on the basis of regional information; a separate set of social equity indicators might be used to reflect social conditions in that region, but these equity indicators are typically not reported in the same framework as the environmental information. The second fundamental of indicator design thus demands that social equity concerns are reflected in all ESD indicators and that, appropriately, *distributive* information becomes an integral part of indicators. It is not uncommon for economic information to be presented in this way; Canadians learned in early 1991 from Statistics Canada, for example, that of the poorest fifth of the population, 16% owned gas barbecues, and that of the richest fifth of the population, 71% owned gas barbecues. We also know that not all Canadians have access to safe water. What is less obvious, however, is how access to safe water depends on income. Do the poor have less access? Is it getting worse? Such questions — of key policy interest during a time when social equity is one of three cornerstones of sustainable development cited by the Brundtland Commission — can only be answered if indicators explicitly reflect such distributional aspects.

Fundamental 3: Projective Applications

The third policy issue, that of *when* things will happen, has traditionally been dealt with by concentrating on existing or past conditions through "bottom-line" indicators. This has often been adequate when policies were largely concerned with *reacting* to existing conditions. But policy-makers are now often being pressed to implement *proactive* policies which are meant to prevent or produce specific effects at some future date. This requires that information made available to policy-makers will also be useful in a *projective* mode. The various types of "projective applications" are explored in further detail below.

Figure 3.
SOME KEY POLICY QUESTIONS:
DERIVATION OF THE FUNDAMENTALS

	Traditional Approach to Indicators	An Augmentation: New Fundamentals
Where are we in relation to the whole?	We concentrate on the immediate obvious needs of humanity.	We adopt a *broader scope* and acknowledge that humanity's longer-term needs require maintenance of the ecosphere.
Who is affected by events?	We concentrate on aggregated information; social equity concerns are captured by separate aggregates of information.	Social equity concerns are reflected in all indicators; *distributive* information becomes an integral part of indicators.
When will things happen?	We concentrate on describing existing or past conditions through "bottom-line" indicators.	We extend our descriptive approach to a projective mode.
What will happen if...?	Indicators generally concentrate on linkages between different types of economic activity.	We extend the indicators to capture the impacts of economic activity on broader ecosystem health.
How good is our information?	Descriptive indicators are assumed to be precise; imprecision is captured through quantifiable risk.	Projective indicators must reflect ecosystem uncertainty.

Fundamental 4: Explicit Linkages

The fourth policy issue deals with identifying and describing the various existing cause-effect relationships. The "*what if?*" question is being asked more frequently in a context where policy-makers are faced with a multiplicity of instruments. Traditional approaches to indicators have focused on linkages between various types of economic indicators: conjectured relationships between interest rates and employment, for example, assist policy-makers in knowing how restrictive monetary policy might exacerbate unemployment problems. Information relating to such linkages has been important to informed decisions regarding "tradeoffs" between sometimes conflicting goals. By the same token, a fundamental principle for designing ESD indicators should be that policy-makers be aware of the *explicit linkages* existing between economic activity and broader ecosystem health.

Fundamental 5: Inherent Uncertainty

Finally, the fifth policy issue, *how* good the information is, has traditionally been ignored when reporting indicators. Information is usually represented as being precise and, where imprecision exists, quantifiable ranges of risk might — albeit rarely — be presented. But an inherent aspect of ecosystem behaviour and response is that of unquantifiable uncertainty; this uncertainty will persist even as scientific understanding of complex systems improves. On a warm morning we are quite content to take a heavy coat to work if the radio announcer warns that there is a 20% chance of snow and that evening lows might be anywhere between 5 degrees above and 5 degrees below freezing. Yet in policy design it is not uncommon to hear decision-makers demand precise indicators before actions are taken. This demand for precision is, among other factors, a remnant of the traditional approach to representing indicators (and economic indicators in particular) as precise. This

traditional approach is not appropriate where complex ecosystems are concerned, and a final fundamental principle for designing ESD indicators must therefore be that they reflect this *inherent uncertainty*.

The Holistic View and Ecosystem Health

Many of the fundamentals have some reference to the broader ecosphere and its "health". We seek indicators which allow us to project how the ecosystem's health may be affected by our activity. We seek indicators which reflect the uncertainty of how healthy the ecosystem is. All of these cases represent an acceptance that we must adopt a *broader scope*: a more holistic scope which acknowledges that the economy and human behaviour within it are part of a broader ecosystem; a scope which recognizes that ecosystem health is a necessary precondition for the future health of humankind.

But at this stage, the natural sciences are still in their infancy in terms of their ability to describe ecosystem behaviour or responses. Further, there is little consensus of what terms such as "environmental integrity", "ecosystem maintenance", or "ecosystem health" mean at a technical level which can be described by specific indicators. However, analysts are increasingly aware of the fact that important dimensions of the problem can only be addressed through investigating the behaviour of the broad ecosystem rather than only small sub-components of such ecosystems. Complex systems — including ecosystems — tend to evolve and organize themselves continuously; their capacity to do so is important to their continued survival under a variety of stresses. To this end, we can start to think of "ecosystem health" as that which reflects the vigour and productivity of the broader ecosystem and, in particular, its ability to maintain its self-organizing capacity. While the scientific basis for the term "ecosystem health" is still hotly debated, its connotations as a corollary to human health are useful.

From the perspective of indicators, the corollary allows us to draw some relevant parallels. First, the road to understanding and measuring ecosystem health will be no less complex than the road humankind has travelled to understanding and measuring human physiology and health. Second, it allows us to take some of our measurement focus away from humanity and place it more on the ecosphere as a whole. Finally, it underlines that, from a diagnostic perspective, efforts must focus on indicators that potentially give some indication of the integrity of life support systems and broad ecosystem health. One such indicator might, for example, be the number of trophic levels one finds in a given ecosystem; declines in this number could provide critical early warning signs that a system's self-organizing capacity — and health — is declining.

Description, Projection, and Prediction: Changing Perspectives on Information

Another issue that is implicit in many of the fundamentals for ESD indicator design — and explicit in one of them — is that indicators must be useful in a projective mode. This also means that we should have information available to project distributional effects, linkages between human activity and ecosystem health, and ranges of potential ecosystem health corresponding to their inherent uncertainty. It is relevant, however, to pursue somewhat more formally what is understood by "indicators which are useful in a projective mode".

Figure 4 provides a summary of four different classes of information:

a) descriptive indicators;

b) indicators with projective applications;

c) projective indicators; and,

d) predictive indicators.

These information classes have different analytical requirements, different applications, and different interpretations in policy-making.

The simplest indicators are those which are purely descriptive of existing or past conditions. Many state of the environment indicators fall into this class, and they are often referred to simply as "bottom-line" indicators as they essentially represent some end-point description without any indication of what contributes to that particular end-point. They are useful in a *reactive policy* framework because changes in these indicators might signal when some reaction is warranted. As noted earlier, they are less useful when policy-making requires some sort of forward-looking *proactive* approach. But it is important to note that any forward-looking exercise will inevitably involve projections or predictions of these simple descriptive indicators, hence they are an important basis for any forward-looking work. In all cases of descriptive

Figure 4.
CHANGING PERSPECTIVES ON INFORMATION: DESCRIPTION, PROJECTION AND PREDICTION

Information Class	Application	Illustrative "Economic" Examples	Illustrative "Environmental" Examples
Descriptive Indicators	"Bottom-line" description of past or current conditions.	Energy Demand = 340,000 PJ Energy Price = $4/GJ	Energy Demand = 340,000 PJ Mean Global Temperature = 13°C
Indicators with Projective Applications	Analytical description of past conditions.	Elasticity of: Energy Demand to Price = -0.8	Elasticity of: Mean global temperature to energy use = 0.005 [Example only]
Projective Indicators	Projection of future conditions based on explicitly stated scenario.	"Energy Demand will fall 8% over long-term if a 10% end-use tax is applied."	"Global temperatures will be 0.1C° less than they would otherwise be if a 10% energy end-use tax is applied." [Example only]
Predictive Indicators	"Bottom-line" unconditional prediction of future conditions.	"Energy prices will increase 2% per year in real terms over the long term."	"The globe will warm by 1C° as a result of past greenhouse gas emissions." [Example only]

indicators, however, the information requires only collection of the data and limited straightforward analysis (through aggregation or normalization) to provide the required information.

At the other extreme, one can describe a class of "predictive indicators". These are usually represented as bottom-line predictions of what is expected to occur in the future; they are usually unconditional, represented as precise, and based on some type of scientific or socio-economic "law" or understanding of what is going on. The assertion that the sun will engulf the earth in about 5 billion years is one such prediction. Other examples in economic and environmental science are described in Figure 4: some economists believe, for example, that real price increases for energy are inevitable because of underlying economic "laws"; some climatologists will similarly assert that — based on their understanding of global systems — a rise in mean equilibrium global temperatures is inevitable given past emissions of greenhouse gases. In all of these cases, however, the predictive indicator presumes that past data have been gathered and analyzed extensively, and that some underlying "model" of the system applies which allows such predictions to be made.

In between these two extremes, shown in grey in the accompanying Figure 4, are the two classes of information which are referred to in this paper as the "projective mode". They require more analysis than the simple descriptive indicators, yet they do not necessarily involve the "black box" structures that are implicit in the predictive indicators. In a sense, these two classes of projective information provide decision-makers with the means to make their own projections. The simplest form of projective information involves "descriptive indicators with projective applications". These are frequently used in the economics discipline and relatively

well-established techniques are available to analyze past data in a manner that is useful to a decision-maker who requires some forward-looking device. The example in Figure 4 illustrates that the own-price energy demand elasticity is approximately –0.8. This means simply that for every 1 percent increase in energy prices, the amount of energy demanded will decrease by 0.8 percent if other factors stay the same. This indicator is descriptive, because it relies entirely on an analysis and description of past behaviour, yet it is useful for forward-looking applications. A conditional projective indicator can be constructed, as shown, which illustrates — based on this elasticity — that a 10% tax on energy will decrease energy use by 8%. In the cases of this projective information, the information requires collection of the data, some detailed analysis (through statistical techniques), and the specification of explicit conditions or scenarios.

The position taken in this paper is that, although most traditional approaches to environmental information have focused on descriptive indicators, information that is useful in the projective mode must be collected and presented to an increasing degree. An illustrative example of this is shown in Figure 4. Descriptive information would give us only "bottom-line" indicators such as energy demand, energy prices, and mean temperatures. If we are concerned about global warming, we might want to know how energy pricing policies will affect global temperatures. This will require us to draw explicit linkages between our activity (energy use) and the condition (temperature) of the broader system. Suppose, for example, that atmospheric studies suggest that equilibrium temperatures will increase by 0.5% for every doubling in energy use; the implied "elasticity" would be 0.005. If we know the energy demand elasticity, we could project that global warming would be "slowed" by 0.1C° — if we were to put in place a 10% energy end-use tax.[2] This information would then provide one element of the total information set available to decision-makers. Other elements of the information set might still include, for example, the linkage of this temperature change to sea-level rise; the linkage between sea-level rise and net losses in output in coastal areas; the critical level of temperature change that ecosystems are likely to be able to withstand before their "health" is threatened; and some indication of the confidence levels associated with all of these.

Summary: Indicator States vs Information Slates

Traditional approaches to environmental information have generally focused on the descriptive "states" of individual indicators. In a broader policy-making context, such descriptive indicators will by themselves be inadequate, although they provide a good starting point for expanding the information which policy-makers will require. An expanded information "slate" provided by indicators which reflect the five fundamentals is more useful to decision-makers than is the "state" of any single indicator.

In some cases, generation of the larger information set will require additional research and improvements to the current state of ecosystem science. Much of this information, however, can be presented using currently available analytical techniques. It will be seen, for example, that the tools of applied economics are well-suited to analysing problems dealing with distributive questions, behavioural projections, and uncertainty. The current challenge will be in receiving more widespread political endorsement of the new fundamentals as a valid and useful part of any framework for collecting information relevant to decision-makers.

[2]The 10% tax would yield a decrease of 8% in energy use. This would yield a decrease of 0.005x8%=0.04% in equilibrium temperature. As the mean temperature is 13°C (or 286°K absolute) the decrease is 286x0.04%=0.11C°.

3 A Closer Look at Issues of Indicator Demand

Introduction

Although the most contentious issues addressed often deal with ecological theories, economic theories, or ethical prescripts of what type of indicators *should* be reported, the ultimate end-user of the information may not be aware of, or may not care about, such issues. From this perspective, it is appropriate — before looking at the ecological, economic, and ethical issues — to concentrate first on issues of indicator demand. Such demand issues have more to do with how indicators are used, rather than with how they can or should be constructed.

Indicators in Decision-Making

Many types of issues can be addressed when considering the use of indicators in decision-making, but we shall concentrate on three here:

a) how might *specific indicators* be used in individual decisions?

b) how do specific indicators relate to *other information* available to decision-makers?

c) how do indicators fit into the overall *decision-making environment*?

In answering the first question, the concept of an "Objective-Input-Constraint Trilogy" can be helpful. In this construct, specific indicators can be thought of as taking on one of three different roles in the decision process. As objectives, indicators would themselves represent some given target. As inputs, an indicator is relevant to the decision process but it is usually implicit that some trade-offs will be necessary between various input indicators. As constraints, indicators are important to the decision-maker as they provide some sort of boundary for action: transgression of the constraint might be physically impossible or, more commonly, might lead to consequences which are regarded as unacceptable.

Within such a framework, there can be significant debate over whether particular types of indicators should be regarded as constraints, objectives, or inputs. Irrespective of this debate, however, one important conclusion is that the way indicators are used can itself be dependent on what the information set is. For example, information sets which provide only "bottom-line" descriptive indicators tend to promote decision processes which regard these indicators as objectives or targets. In principle, for example, projected CO_2 concentrations might be an important input (or constraint) to determining how we should organize economic activity. In practice, however, if we concentrate only on measuring CO_2 concentrations, then the CO_2 level itself tends to become the objective when the actual objective should be regarded as something more general (such as sustainable development). An effective means to ensure that policies are not driven entirely by the "bottom-line" is to design information sets of ESD indicators that are potentially useful as *projective* tools in addition to their more traditional function as descriptive tools.

The second question, relating to the use of other information, is also open to considerable debate. One important aspect of this has to do with the "rationality" of a given decision process. The point of debate on whether decisions are "rational" is generally associated with two quite different dimensions: an intuitive dimension which means "sensible"; and, a formal dimension, common to the economics literature, which can be more or less construed as "consistent". In this context, consistent behaviour would — from an economist's perspective — be entirely rational, even though the behaviour might not seem at all sensible. Conversely, something might seem *irrational* under the formal economist's definition, yet still quite sensible intuitively. If I preferred apples to oranges, oranges to bananas, and bananas to apples, an economist might think I was irrational even though to me it is a perfectly sensible preference ordering.

Although debate on such issues will not be resolved easily, the debate has two general implications for indicator design. First, it highlights that the amount of information required — in addition to the specific indicators — will to some degree depend on whether decisions were made in a "single-objective" or "multiple-objective" context. Where multiple objectives, or a plurality of views, exist, more information about the trade-offs and linkages between various indicators is required. Second, decision processes themselves might become better understood if we had more information on the linkages between various factors. To illustrate this point, we can return back to the "apple-orange-banana" example. When this "inconsistent" pref-

erence ordering was first observed, it was regarded by many as irrational: but when economists made further investigations they discovered that the preference ordering was both consistent and sensible if one measured, not items like apples, oranges, and bananas, but *characteristics* such as texture, colour, acidity, juiciness, and so on. When characteristics were ranked for each fruit, and when respondents were observed to select preferentially always that fruit which was dominant in more of the favoured characteristics, it became clear to researchers that they had been measuring the wrong thing all of the time: they should have been measuring *characteristics* instead of *items*. In short, by understanding the actual linkages and trade-off relationships which exist, it provides a basis for designing better future indicators.

The third question, that of the decision-making environment, relates to whether different indicators are required in different policy environments. Some argue that less information is required in market economies than in controlled economies, because the market will, to some degree, generate its own information requirements with no intervention. The opposing view is that market economies must have more information because they are involved in a wider range of activities, some of which are potentially quite destructive to the environment. While this debate will continue, one conclusion is that the types of indicators supplied might themselves influence the type of decision-making environment which arises. Descriptive indicators that are represented as targets or constraints might, for example, tend to promote regulatory approaches to policies. Indicators that provide information about *linkages* and trade-offs, and imply some flexibility in response, tend to promote decision-making environments that are less "command and control" based.

Indicator Communication

A concern which regularly surfaces relates to how much information is actually required. Is there such a thing as "too much" information? There are many dimensions to this, but at this stage the answer seems to be a qualified "yes". The types of reasons given for this are:

a) information costs money and at a certain point the cost of obtaining additional information is simply not worth the extra benefit which decision-makers might derive from that information;

b) having a little bit of data which are "crude and available now" is better than having a lot of data which are "precise but available later" in circumstances when time is of the essence;

c) an overload of detail does not help people who need to make general conclusions; and,

d) if not all types of information are being gathered, then it is possible that too much detail of one sort will lead to incorrect policy decisions. Indicators which report instantaneous trends might provide an incomplete picture of longer-term underlying behaviour; policies based only on these short-term trends will be fundamentally flawed.

By contrast, some take the position that simple indicators should be abandoned because only comprehensive sets of information can provide decision-makers with the type of information required to make proper decisions. Under this view, composite indicators are also not appropriate because they fail to reflect causal or behavioural linkages. Although support for all of these positions is likely to persist, it is clear that information must take into account the target audience: some audiences will require, and will be able to understand, more detailed information than others.

The second concern in indicator communication is thus the actual target audience. Indicators are used for a multiplicity of purposes by a wide array of users. Individual citizens organize their own consumption behaviour in response to indicators; scientists need technically detailed indicators to get a better handle on how systems behave; policy-makers need behavioural detail in indicators to determine what policy responses might be required to achieve particular objectives; decision-makers in corporations require information specific to their corporate sector or market region. In all such cases, however, an important piece of information involves the *incidence* of any particular event: regional authorities require regional disaggregation of indicators and individual business people will require information specific to their own industrial sector. The simple message is that, irrespective of what is being measured, some form of *distributive* disaggregation is an important component of any indicator.

Within the policy-oriented target audience, there is also a growing recognition that "stewardship" of the environment will become a potentially important responsibility. Stewardship implies that some management will be required; man-

agement will only be successful if information on behavioural linkages exists which is useful in *projective* applications.

A final issue in indicator communication relates to education. There are, in fact, two distinct dimensions to the role of education in indicator design. The obvious dimension, on which people normally concentrate, is that indicators are meant to educate the public, policy-makers, or some other target audience. A second, and perhaps more important dimension of ESD indicators, is that *education must be provided to describe what the indicators mean.* This can be done either through trying to provide long explanations of what the indicators mean, or by making the indicators themselves somehow tie to something with which people are familiar. A classic example has become indicators of "wind-chill" factor. Wind-chill describes the rate of heat loss from exposed flesh under various combinations of air temperature, wind speed, and wind direction. A technically correct measure in terms of $kJ/m^2/sec$ is likely to require a great deal of explanation; an equivalent temperature measure (e.g., 50^{o} below zero) is technically less correct yet intuitively better; and an actual projected impact measure that incorporates typical cause-effect relationships ("exposed flesh will freeze in 30 seconds") is better yet as an indicator which is readily understandable without separate explanation.

Within the design of ESD indicators, this highlights the idea that for indicators to have some "self-explanatory" power, it helps to use concepts with which people are familiar. While the loss of one trophic level in Lake Erie might be important, it is also helpful if this could be connected to something like the concomitant decrease in sport fishing catch or the accompanying cost of water treatment. Failure to make such connections explicitly through education, or implicitly through indicators which are more intuitively self-explanatory, means that many indicators will be regarded simply as a scientific curiosity even though they might be very relevant indicators of ecosystem health.

Summary

The design of ESD indicators must be sensitive to how these indicators will be used and who will be using them. An investigation of the demand issues provides a strong case for introducing two of the fundamental principles: indicators should have *projective* applications; indicators should have *distributive* elements. In addition, it is clear that some description of the linkages between certain types of information would be helpful to decision-makers and to understanding the decision-making process itself.

4 A Closer Look at Issues of Indicator Supply

Introduction

While the uses and audiences for ESD indicators are quite varied, our actions are ultimately bound by what can, in reality, be generated given any particular set of theoretical premises or practical constraints. Such theories can be regarded as supply issues to the extent that they depend on some ethical or practical reason which might limit the types of information that should or can be presented. One key lesson from investigating these supply issues is that different economic, ecological or political paradigms will generate different conclusions of what appropriate specific ESD indicators are. Some further generalizations for indicator design are made in this chapter, however, from investigating issues of social equity, ecological sustainability and economic sustainability. In summary, the chapter briefly addresses some issues which cross-over between these areas.

Social Equity and Ethics

The social equity and ethics dimension of indicators arises in numerous contexts. The first, and most notable, observation is that the ethical dimension can enter into indicators in two fashions: *what* indicators are specifically presented; and, *how* that presentation is interpreted. For example, we might have indicators which present information that dolphin populations are declining, or that the number of poor people without access to safe water is increasing. The presentation of this information captures the first element of the social ethics dimension. However, the second element, concerning how we interpret the information, is a quite different issue. Those with a broad world view might be outraged by the information, those with other priorities might be indifferent. Although it is not expected that everyone will take the "world view", the fact that more nations and individuals are taking this interest demands that the "what" dimension of social equity be presented more carefully. As implied by the previous chapter, however, the very fact that this type of information might be presented will at times force the interpretation issue: currently some of this information is not presented and it leaves people with the opportunity to live contentedly behind their "veil of ignorance".

Regardless of how we interpret it, the upshot is that more information is required about "what" is happening or will happen in the social equity dimension. From a practical perspective, there are basically two methods of dealing with indicators of social equity: a separate information set; or, an additional dimension of information that is reflected in all other indicators. The traditional approach has been to present a separate and distinct set of indicators of social equity through presenting indicators such as general poverty line statistics, or information on specific social groups within society. Presentation of this information has always been distinct from environmental information, although it is often tied into economic information. A new approach is called for. Because of the differential economic and physical impacts of environmental problems, a strong case can be made for explicitly showing the *distributive* elements of any such problems by social or economic group.

To distinguish more clearly between the various dimensions of these distributive elements, Figure 5 highlights three types of disaggregation. The first, with which most people are quite familiar, deals with the geographical or sectoral distribution of environmental problems. This is what the discussion in Chapter 3 relating to target audiences focused on: different public policy-makers or corporate decision-makers will often require this level of disaggregation to make decisions for their specific jurisdictions or economic sectors. This is also the dimension reflected in most international comparisons and, when previous studies have provided "disaggregated indicators", this is the type of disaggregation which has usually been supplied. An explicit social equity focus should also pay attention to the two other dimensions of this disaggregation: that relating to socio-economic status; and, that relating to intergenerational equity and the timing of the impacts. The former pays attention to the distribution of impacts according to nationalities (aboriginal nations), gender, age, education, or other facets. The latter requires that we pay attention to the timing of impacts and which generation will be responsible for bearing the consequences of our actions. For indicators, this requires that we have some *projective* abilities available. While there is considerable disagreement over what we should or should not leave future generations, we will still need to have the information about those consequences at hand to decide whether those consequences are or

Figure 5.

SOCIAL EQUITY INFORMATION AND THE DISTRIBUTIVE DIMENSION OF INDICATORS

I: Disaggregation by Sector and Geographic Region

Consumption Sector: Residential, Commercial, Industrial, Government, ...
Production Sector: Energy, Forestry, Fisheries, ...
Political Jurisdiction: International, National, Provincial, Regional, Municipal, Rural/Urban ...

II: Disaggregation by Socio-economic Status

Age Cohort
Sex
Education Level
Income Group
Cultural Group

III: Disaggregation by Time of Impact

Current Generation in Current Time Period
Current Generation in Future Time Periods
Future Generations in Current Time Period
Future Generations in Future Time Periods

are not acceptable to us. Again, a clear distinction must be made between the "what" and the "how" questions introduced earlier.

Hence, social equity concerns require that the distributive elements must go beyond the regional or sectoral incidence described earlier; they must also show how different economic groups — the poorest and wealthiest, for example — are affected by given environmental problems. Concerns for minority interest groups or the economically disadvantaged have become more central to decision-making both domestically and internationally. As there has been a relative lag of reporting and analysis efforts in this area, it is appropriate for the social equity dimension to become a more dedicated focus for future ESD indicator design.

In summary, returning to the issue of "how" to interpret this type of distributional information, it would be presumptuous to assert that we know what is "good" or "bad". As one workshop participant observed, humans typically have trouble deciding what is "good" and "bad". The compromise which many adopt is a rejection of "absolutism" and an adoption of "relativism": the very adoption of such a compromise is, however, likely to increase the information requirements for comparative and *distributive* types of information.

Ecological Sustainability: Towards New Principles

In designing ESD indicators, the concept of ecological sustainability will force us to pay particular attention to introducing a "broader scope" and "inherent uncertainty" into the indicators which are presented. The following investigates some key issues which lead to these conclusions.

The natural sciences are, as noted earlier, still in their infancy in terms of their ability to describe ecosystem behaviour or responses. While the connotations associated with "environmental integrity" appear to be an appealing goal, there is little consensus of what it means at a technical level, and whether it is an appropriate target in any event. A typical connotation of "environmental integrity" among policy-makers has been that we must try to keep something — primary rainforest, for example — intact by ensuring that it is not subjected to any destructive stresses.

Within ecosystem science, however, some would argue that any type of steady state situation is inherently unstable and that, in any event, ecosystems require some amount of external stress to ensure that their ability to adapt is not threatened. In this view, a "hands-off" approach is not necessarily required.

The idea of "environmental integrity" thus warrants some careful reconsideration. Various views propose that a better target would be to implement policies which promote ecosystem "maintenance", ecosystem "health", or — in some instances — ecosystem "development". While the views differ considerably, any of these positions requires that attention be paid not just to what is happening to people, but also to what is happening to ecosystems. As noted earlier, it is useful to regard the concept of ecosystem health as a close corollary to human health. Various indicators of ecosystem health might be appropriate — such as trophic levels, cycle lengths, or the populations of keystone species — and the actual selection of indicators will differ among ecological theories. Nonetheless, this does not detract from the idea that indicator design must reflect a *broader scope*.

This broader scope can take a number of directions. One avenue, however, is to start looking for appropriate diagnostic indicators of ecosystem health. These might have little obvious to do with human health. Examples of such indicators would include keystone species, charismatic species, or indicator species. Indicator species are especially useful if they can provide us with some sort of early warning sign that something is going wrong; canaries, which are more sensitive to trace concentrations of dangerous gases than are people, provided effective early warning systems when accompanying miners into mine shafts. A second potential avenue is to use the notion that humans themselves can be an indicator species, although it must be realized that human health impacts brought on by external stresses may be slow in manifesting themselves. While a decline in general human health — such as increased incidence of asthma attacks or radiation-related diseases in a given area — cannot be an effective *early* warning system for human health, it might be an indication that the broader ecosystem is also being subjected to intolerably high stresses. Using humans as an indicator species has the obvious advantage that we already have a vast network in place to gather information on human health: we simply need to start analysing it from a somewhat broader perspective.

What we do know about ecosystems, however, is that they do not behave with well-defined precision. Analysts are becoming increasingly aware that important dimensions of the "ecosystem health" problem can only be addressed through investigating the behaviour of the broad ecosystem rather than only small sub-components of such ecosystems. Unquantifiable uncertainty (as opposed to distinct quantifiable risk) is an inherent aspect of ecosystem behaviour. Indicator design must, where possible, reflect this inherent *uncertainty*; it is especially important that indicators do not appear to provide a greater degree of precision than they are, in fact, capable of providing.

Economic Sustainability: Towards New Principles

While different ecological theories will advocate different indicators of ecosystem health, different theories of how economies work — or of how economic measurement should be conducted — will result in different indicators of economic well-being. The general lessons from the economic sustainability debate, however, are that we will have to rely increasingly on describing the *linkages* between economic activity and the broader ecosystem, and that we must have some *projective* ability to do so. The following investigates some key issues which lead to these conclusions.

A particularly important lesson of economic sustainability is that conventional notions of economic "growth" are potentially misleading. Many indicators which traditionally provided measures of this growth are also inadequate for reflecting economic sustainability. Decisions based solely on aggregated GNP, for example, are flawed as this measure does not reflect the physical degradation of environmental capital and the monetary divestment of renewable resource inventories that occur in making up the GNP. Indicators of economic sustainability must, in this respect, be sensitive to the idea that the economy is, in fact, simply a subset of a larger ecosystem; indicators must reflect both the *linkages* between the economy and the ecosystem as well as the idea that the broader ecosystem is also of fundamental importance.

Appropriately, some reorientation of the concept of economic growth is warranted. Different approaches to this reorientation arise. One approach holds that we should concentrate on something quite different called "economic

development"; this requires paying attention to how overall quality of our economic well-being changes. This, it is asserted, might be done either with or without conventional economic growth. The approach requires that we extend indicators to measure quality of economic life, quality of the environment, quality of education and intellectual capital, quality of political and social freedom, and other factors not normally captured within conventional economic growth measures.

A second approach holds that we can still speak of conventional economic growth, but that we must start paying more attention to what the physical constraints are to that growth. There is considerable sympathy with the view that natural capital, in some form or another, is becoming the new constraint. Traditionally, human or man-made capital was often regarded as the constraint to economic growth. To establish whether the "natural capital constraint" idea is correct, we must have information on the specific linkages between human activity and the broader ecosystem which supports it, and might ultimately constrain it.

A somewhat related issue deals with whether humanity has actually been "living off" of natural capital to the detriment of the natural environment. While debate will continue on how to interpret the definition and valuation of natural capital, the issue will again be resolved only by explaining the linkages more clearly.

Describing the economy-environment linkages has led to many different approaches to monetizing the environment. There is continuing debate over whether such hypothetical monetization is appropriate and, if it is, which techniques should be used. Regardless of the techniques, most of the monetization approaches have one thing in common: they are trying to provide a better description of the linkages which exist between the economy and the environment. One example also illustrates how the role of projective information is becoming more important. There are ongoing efforts to reform the way that the System of National Accounts is handled and presented; one reform involves adjusting national income statistics to reflect the costs of environmental damage. A question being addressed is whether the appropriate costing figure should be "restorative costs" or "preventive costs". While there are numerous ecological and economic aspects to the debate about which measure is more appropriate, an important point is that both will require some projective ability. In one case we are estimating costs to restore something to some projected future state; in the other case we are projecting expenses to ensure that some future state will be maintained. Concentrating just on past or current information will not in itself provide us with the necessary insights we are seeking.

Summary

It is notable that the three themes examined above also reflect the cornerstones of what the Brundtland Commission in 1987 characterized as "sustainable development". The bulk of international attention, however, has been directed towards the environmental and economic aspects of these three: social equity aspects have often run a distant third in terms of the amount of attention they have received. In addition, indicator development has initially focused on economic behaviour indicators and descriptive "bottom-line" environmental indicators. One of the reasons that economic indicators have received such a large and dedicated following is precisely because, unlike many environmental and social equity indicators, they reflect some elements of system *behaviour* which allow decision-makers to project their direction. Such *projective* possibilities are only available to a limited degree with "environmental" indicators, and virtually no effort has been made to integrate social equity concerns into either economic or environmental indicators. It would thus seem that some priority should be placed on moving the "environmental" indicators into the same realm as economic indicators: a realm in which projective applications and descriptions of linkages is the norm. Similarly, "social equity" indicators have even further to go to catch up: a good first step will be to start integrating distributive information about social equity explicitly into all ESD indicators.

The three themes also provide an interesting perspective on the *scale* issue. The recognition that human activity is a subset of the broader ecosystem is one manifestation of the idea of scale; ecosystem scientists tell us that ecosystems might behave differently at different scales. But this is a concept with which we should already be all too well familiar. Corollaries can be found in the the equity dimension: some regard that the use of minimal force in defence is acceptable; the use of overt force in isolated incidents is not generally supported but often overlooked nonetheless; the use of overt force on a continuous or massive basis is regarded

as critically unacceptable. Similarly, in economics, post-Depression governments discovered that deficit financing was an effective way to pull the economy out of a slump: it was effective because the government sector was relatively small compared to the economy as a whole. As the public sector grew, and as public debt grew, deficit financing became a less effective vehicle. In some countries today, where the scale of the debt and the scale of the public sector is very large, trying to spend one's way out of a recession on inappropriate investments could lead to complete degradation of the system. To conclude, all systems — economic, political, or ecological — display behaviour which is scale dependent. When we accept this, we will realize that it is also important to know how systems behave at different scales, what the critical scales are, and what happens once systems approach those critical scales.

In summary, an investigation of the supply issues provides a strong case for introducing the following fundamental principles: indicators should reflect a *broader scope* which places increased importance on ecosystem health; indicators should reflect *explicit linkages* between economic behaviour and ecosystem health; indicators should recognize the *inherent uncertainty* in ecosystems. Strong support is also provided for the *projective* and *distributive* requirements of ESD indicator design.

5 A Closer Look at the Analytical Tools

Introduction

The previous chapters described how some technical issues of indicator "demand" and "supply" can lead to the need for some new principles of ESD indicator design. A key conclusion was that indicators that are purely descriptive of past or current circumstances provide incomplete information. These descriptive indicators are incomplete because they do not reflect any underlying behavioural linkages, they provide no time dimension which might be used in projective applications, they seldom reflect distributional concerns of a social equity nature, and the dimension of inherent ecosystem uncertainty is typically not given. But it is recognized that all information will, eventually, be based on or derived from some form of descriptive indicator. It is therefore clear that adoption of the new fundamentals for designing ESD indicators requires the application of some form of analysis.

While subsequent chapters will illustrate more specifically how certain techniques can be applied to present this information, this chapter will provide a brief overview of some selected issues dealing with analytical tools. Background work to the workshop provided a review of potentially useful analytical techniques.[3] This chapter will thus simply reiterate some of the key conclusions, and then address some new areas which were identified at subsequent workshop discussions.

Different Analytical Approaches: Some Observations

Numerous analytical tools are available for dealing with both economic monetary information and purely physical information. Technical models can describe technical linkages between various activities' output and input requirements. Economic models can describe these linkages in monetized terms, or connect monetary parameters to physical parameters. Modelling techniques using both descriptive and projective techniques are used routinely within the behavioural sciences.

In short, the behavioural sciences — economics among them — have progressed well beyond the descriptive stage and have developed substantial analytical means for projecting the impacts of policy initiatives on human activity and welfare. Further, tools and conventions to deal with distributional questions are well-developed in this discipline, and data are often organized in ways which can accommodate both distributional and projective analyses. Finally, an ecological tradition of modelling the demographics of a small number of inter-related species has been effectively adopted by natural resource economists to assist in management decisions relating to specific populations. It would appear, therefore, that much of the required "infrastructure" to generate the types of data referred to in this paper is in place in the behavioural sciences. However, there is a lack of consistent means for integrating ecological information into this framework.

Some approaches appear more promising than others. The most frequently cited, and called for by decision-makers, is the need to determine how ecosystems might constrain human activities. This requires that constraints be built into existing modelling frameworks such that the economy is forced to operate within this constraint. It is recognized that, within any such "model", the constraint is in fact an artificial simulation of what is in fact an uncertain parameter. It is therefore also important to make such constraints flexible so that uncertainty in ecosystems can be explicitly accommodated within policy analysis.

A second area of concentration is in more explicit modelling of linkages. Complex linkage models of economies already exist using a wide variety of approaches. In addition, the use of "effects" modelling in the biological and natural sciences is becoming more common. The purpose of effects modelling is to illustrate the isolated impact of some parameter on a broader system. Some partial integration of the economic and ecological modelling techniques — at least at the boundaries of each of the modelling systems and, where possible, at more than one point on the boundaries — is both feasible and desirable.

A third area, which also has some limited potential, deals with the parallels between economic general equilibrium models and an emerging

[3]See Ruitenbeek (1991), "The Role of Indicators in the Decision Process" in *Economic, Ecological, and Decision Theories: Indicators of Ecologically Sustainable Development*, CEAC: Ottawa.

view within some theories of ecosystem science that we must try to describe and model the entire system rather than small parts of it. Analogues to this approach can also be found within economic modelling. Experience with the economic models has been that modelling in just one variable can be effective in a short-term projective mode, but largely ineffective in a long-term projective mode. Modelling in a small number of key variables of economic performance has in some instances been able to project economic system behaviour reasonably accurately. The primary potential problem for the ecological sciences is that they may not have the historical data available on ecosystems that economists have available on economies. The historical information set available to economists does, however, offer potential proxies for ecosystem "health". Review of the information set, and analysis of the data within it, is warranted to determine if some adequate proxies can be found. As noted in the previous chapter, one potential candidate is human health. Through tracing this back, techniques (such as multivariate analysis) can be used to try to establish linkages between economic activity and broader ecosystem health.

Some Appropriate Techniques for Addressing the New Fundamentals

Quite remarkably, the type of indicator which has received the least attention to date, yet which is the simplest to create with the analytical tools available, involves information relating to the *distributive* dimensions of social equity. Both disaggregated and composite indicators have been used extensively within economics to try to report measures of income and asset distribution. The usual approach to the disaggregated information is to report indicators for separate income quintiles or deciles. Simpler means report information just for specific groups below certain income cut-off levels. The more frequent use of economic household survey data (typically sampling 50,000 or more households) and experimental surveys based on analyses of income tax returns, has provided information sets rich with disaggregated information.

The provision of distributive information, as well as that involving linkages between economic activity and ecosystem health, is greatly facilitated by geographical coding of information. The actual practice of "geo-coding" economic information is already quite common because the same type of information is required for decision-makers wishing information on particular jurisdictions. In addition, GIS systems are becoming more routine for presenting environmental information. What is less common, however, are the necessary links which would allow one to tie these two sets of information together. One good example of such links being established is the Statistics Canada publication *Human Activity in the Environment.*

In addition, the use of composite poverty and inequality indices has a long history in economic science although the most commonly used — the "GINI Coefficient" of inequality — has fallen into disuse. While part of the demise of this particular composite indicator has to do with some unusual (and often thought undesirable) characteristics it displays when income shifts within the middle income ranges, it can be more generally commented that composite inequality indices are now used primarily for specific policy questions; they are not usually presented or understood by the general public or by most decision-makers. When they are targeted to decision-makers, they are usually presented in both a disaggregated and a composite format.

Techniques for establishing both projective indicators and explicit linkages will, to a large degree, need to rely on multivariate analysis of historical or cross-sectional information. The basic idea is that one attempts to obtain enough data points to have a statistically significant sample such that one can distinguish between random "noise" in the data and the influence of independent factors. For example, one might try to "explain" urban pollution levels in terms of variables such as outside temperature, windspeed, number of automobiles, price of gasoline, average incomes, and some proxy for rush-hour congestion. If historical measures are available for one or more cities, then there is opportunity to isolate the effects of just, for example, gasoline prices or rush-hour congestion. A coefficient which describes only the *isolated* or *partial* linkage between one factor and another is generally termed an impact elasticity. An elasticity of –1 between gas prices and pollution, for example, would indicate that increasing gas prices by 10% would decrease pollution by 10% if all of the other things were kept constant. Similarly, investigation of the "rush-hour" variable might suggest whether policies to try to stagger rush-hour traffic might decrease pollution.

One extension of multivariate analysis to describing linkages involves a set of tools called

"limited dependent variable" techniques. These are becoming more common in economic analysis as economists are being forced to deal with fewer quantitative data and more qualitative data. The basic idea is similar to standard multivariate analysis, except that the dependent variable — the one you are trying to explain — takes on the value of only two or three distinct states. The use of this technique was pioneered for purchasing decisions: I either buy a car or I do not buy a car; I either drive a car or I take the bus or I walk; and so on. More recently, it has been used to model impacts of human activities on various ecosystems: I either hunt or I do not hunt; I either chop down trees or I buy kerosene. As a next extension, such techniques might be applicable to modelling (after the fact) when ecosystems have apparently moved from one state to another.

Although the tools of risk analysis are also relatively well developed, many of the formal mechanisms for dealing with quantifiable risk are not applicable in the context of inherently unquantifiable ecosystem uncertainty. Uncertainty is best reflected through scenario analysis that embodies explicit potential outcomes in terms of economic and ecosystem behaviour. The use of ranges of *critical values* is a particularly relevant and tractable method for presenting ESD indicators. Such methods are consistent with the idea that ecosystems exhibit inherent uncertainty, while also presenting relevant information to decision-makers regarding how close we are to certain limiting factors. In addition, they provide important planning information for "worst-case scenarios"; such scenarios are often cited as being *one* important input into the overall decision process. Key requirements for establishing critical sensitivity analyses, however, are that natural scientists must assist in defining a range of "critical levels" for an ecosystem, *and* give some idea of what happens at that critical level.

Summary

The previous chapters illustrated that information will, in principle, extend beyond simple measurement and reporting into realms that require further analysis and interpretation of the raw measurements. Indicators that are useful in projective applications, or those that reflect explicit linkages between the economy and ecosystem health, for example, will rely on analytical techniques which themselves have different information needs.

Analytical techniques involving economic analysis of behavioural, distributive and projective information are among the most common and well-developed techniques. Many of these can be, and have been, adapted for uses which accommodate technical information of the type which might be generated within the natural sciences. A significant first step — in many such exercises — will involve introducing ranges of physical ecosystem constraints within the analytical frameworks. The advantage to such an approach is that it is consistent with the idea that the economy is a subset of a broader ecosystem; it also has, at this stage, the most modest level of information demands on the natural sciences, and will lead eventually to a better understanding and development of indicators that reflect the economy-ecosystem linkages.

In summary, the analytical tools for dealing with both technical and economic information are well developed for providing information that is consistent with the five new fundamentals. The primary challenge is to increase the level of interdisciplinary work that occurs between the social and natural sciences to ensure that these tools are used to their full potential.

6 The Role of Public Policy in Ecosystem Health

Introduction

A review of some of the technical issues of ESD indicator design has resulted in the enumeration of five new fundamentals. Additionally, to underline the linkages between these issues and their ultimate applicability to policy decisions, it is useful to consider how indicators based on these fundamentals reflect a new focus for public policy. While public policy has traditionally been concerned with human health and welfare, it is also now finding a new role in addressing ecosystem health. This chapter explores some of the key factors that have contributed to this new role, highlighting how ESD indicators will provide important information in each step of the process of designing appropriate policies. A general example of a set of indicators is provided to illustrate how the five fundamentals contribute to a framework that is useful to this new role for public policy; the following chapter will look at a more specific set of indicators with numerical examples.

The New Public Policy Focus

The new role of public policy is most easily shown in Figure 6. While the traditional focus of public policy has been on short-term human health and welfare, the new focus also recognizes that public policy can play an important role in addressing ecosystem health. The new focus has evolved for a number of reasons, but it is useful to look at two of them at this juncture.

Considerable discussion arose during the workshop relating to whether humanity is or should be "anthropocentric" or "ecocentric". While the actual semantics of these terms is open to wide interpretation, essentially two quite different substantive positions exist. The first position — which might be characterized as the "forward-looking anthropocentric view" — holds that humanity's own long-term welfare depends on the continued vigour and productivity of the broader ecosystem. Under this view, public policy must address ecosystem health because failure to do so would undermine humanity's own long-term survival. The second holds that ecosystems, the ecosphere, and all natural things have — for moral reasons — some intrinsic value and an inherent right to exist and that humanity must, when organizing its own activities, respect these rights. Under this view, public policy must essentially address ecosystem health as a worthwhile end in and of itself.

Although the ethical bases for these two views are quite different, and not necessarily mutually exclusive, both views lead to the conclusion that public policy must start paying attention to ecosystem health. As shown in Figure 6, our traditional short-term focus has caused neglect of the broader ecosystem to the potential detriment of long-term human health. Although we can still maintain a longer-term anthropocentric attitude, this requires that the orientation of our immediate policies adopts a *broader scope*. Concomitantly, ESD indicators — along the lines of each of the steps identified below — must provide information that is consistent with such an orientation.

Stages of Indicators: Tracing the Connections

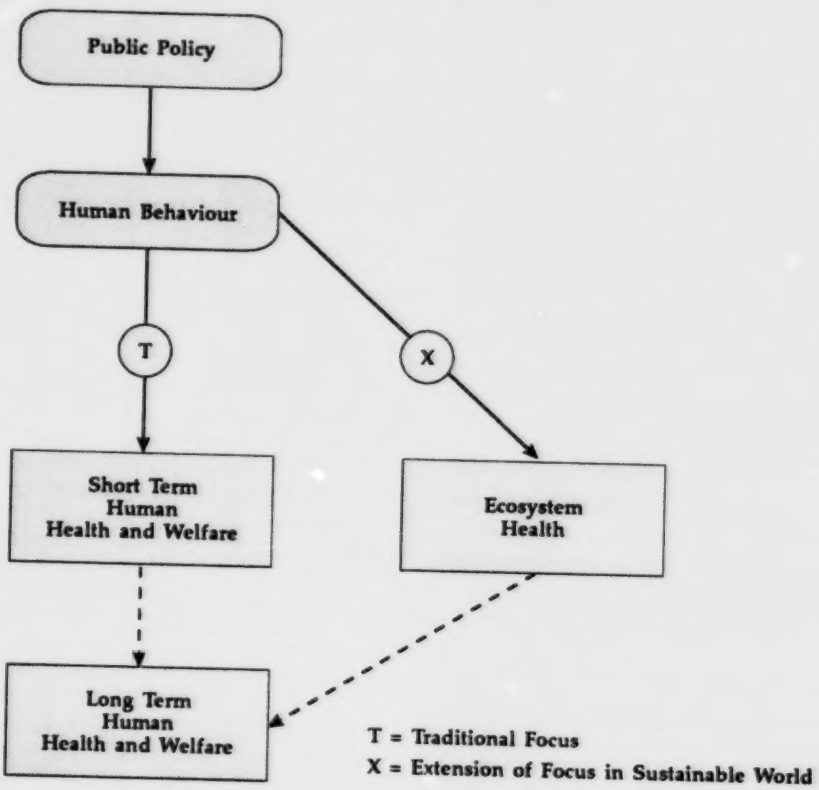
Public Policy and Human Behaviour

The first step in the process is to describe how human behaviour responds to public policy. There are numerous instruments of public policy — such as education policy, migration policy, and economic policy to name a few — and human behaviour in general responds to these policy instruments. Higher taxes on energy cause people to use less energy; open migration policies increase labour mobility. Even the *absence* of explicit public policy intervention presumably has some influence over how people behave either individually or collectively. In any event, in a policy context, it is important to have information that shows how human behaviour responds to public policy initiatives.

Human Behaviour and Short-term Ecosystem Stress

The second step in the process is to describe the impacts of human behaviour on the broader ecosystem. Traditionally this step would focus on how human behaviour influences human well-being through, for example, impacts on available leisure time or on some index of the standard of living. The new focus, however, requires that we trace the linkage between human activities and potential stresses on the ecosystem. Developing information relevant to this step will require

Figure 6.
THE NEW PUBLIC POLICY FOCUS



increased inter-disciplinary work between social scientists and ecosystem scientists.

Ecosystem Stress and Long-term Ecological Sustainability

The third step involves identifying the linkages between general ecosystem health and the various stresses to which the ecosystem is subjected. This step is probably the most difficult to incorporate into typical information frameworks as it essentially falls entirely within a realm of the natural sciences that has not traditionally provided such input to decision-makers. Moreover, the current state of the science, as discussed earlier, does not allow tidy simple answers to be provided about this particular linkage. Some degree of external stress is, for example, likely to contribute positively to ecosystem health, while too much stress will presumably degrade ecosystem health. Also, the degree of the impact of any stress is probably related to the scale of the cumulative build-up of past stresses: a small incremental stress when a system is near some critical threshold is liable to have greater consequences to ecosystem health than would a much larger stress when the system was far from this threshold. In short, "scale" plays a potentially important role as an important factor to determining ultimate impacts on ecosystem health. Providing information to address this third step resides almost entirely within the mandate of the natural sciences.

Long-term Sustainability and Current Policies: Closing the Loop

The final step requires drawing connections between ecosystem health and future long-term human health and welfare. This step again

will draw on the combined expertise of social and natural scientists. It is interesting to note, however, that this step is necessary only if one leans towards the school of thought favouring the "forward-looking anthropocentric view". Those content with addressing ecosystem health as a policy end in its own right would not need this additional information.

The Analytical Requirements

Both the information and the analytical tools required to address this extended policy focus are quite different from those required under the traditional focus. In the context of Figure 6, the traditional focus required two types of information for policy formulation: knowledge of how policies affect human behaviour; and descriptive indicators of humanity's own short-term well-being. The analytical requirements of the new policy focus present a substantial, though not insurmountable, challenge. The following section demonstrates how a set of indicators — based on a framework reflecting the five new fundamentals — could be constructed to address this new policy focus.

A Simple General Example: Near-term Policies and Long-term Impacts

It is important that the new fundamentals be applied on the basis of augmenting the current information set of ESD indicators that are available. While the precise manner in which this is done will differ from one application to the next, the simple example shown in Figure 7 illustrates how new indicators might be developed as an augmentation of existing information. In this example, a simple "bottom-line" descriptive indicator of environmental resource quality is used as a starting point. Through applying both further measurement *and* analysis, the indicators can be expanded to give decision-makers a more complete set of decision support information. Using this set it would be possible for a policy-maker to judge, for example, whether current immigration policies will unduly threaten longer-term ecosystem health. To illustrate some of the practical aspects of designing this information set, each part of this augmented information slate will be examined in turn.

As a starting point, it is useful to distinguish between the "reference indicator" that is often used in traditional policy problems, and an indicator that reflects a *broader scope*. This broader scope can be reflected in one of two ways: (a) through disaggregating the reference indicator to the level of specific ecosystems; or, (b) through providing information that is a diagnostic indicator for the system rather than something that is necessarily important to human health. Figure 7 takes the latter approach: it illustrates that the reference indicator might be some water quality characteristic — such as the concentration of nitrate/nitrite in water — which is important to human health; an indicator of broader scope that might be more relevant as a diagnostic indicator of ecosystem health, however, might be the number of trophic levels.

Incorporating *distributive* elements within an indicator can also have many different dimensions. Figure 7 illustrates one possible disaggregation of the reference indicator that provides policy-makers with information about the consumption of water quality by income class. The use of income "quintiles" is a fairly common analytical technique for presenting distributional data on the basis of income distribution. The basic idea is that the population is divided into five groups — each comprising 20% of the population — such that the poorest are in the lowest quintile and the richest are in the highest quintile.[4] If such indicators revealed that the plight of the less advantaged economically was also getting disproportionately worse "environmentally", cause might be found for targeting policies to selected income groups. It should be noted that "income" is not always the most appropriate or readily available basis for providing such distributive information; a method that is sometimes more analytically tractable involves using some form of asset base to describe the disaggregation (such as "renters" vs "owners"). In developing countries, land tenure positions are often a more revealing — and more readily available — method of disaggregation.[5]

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[4]In Canada in 1989, for example, any household with an income of under $17,000 was in the bottom quintile; any household with an income greater than $64,000 was in the highest income quintile.

[5]In a recent report — World Bank (1990), *Towards an Environmental Strategy for Nigeria* — the effects of environmental degradation (including desertification, deforestation, water contamination, air pollution, and other problems) were estimated explicitly for five "economic groups". The "richest" were defined as those who normally own property, land and have formal sector (wage) income; the "poorest" included those who owned no property, had no access (transient or rented) to land, and purchased most of their food requirements.

Figure 7.
General Augmentation of a Sample Indicator — Water Quality

Reference Point	Water Quality Characteristic Important to Human Health (Q_h)
Broader Scope	Water Quality Characteristic Important to Ecosystem Health (Q_e)
Explicit *Distributive* Elements	Average Water Quality Consumed by Lowest and Highest Income Quintile (y) of Population ($Q_{h;y=1}$; $Q_{h;y=5}$)
Applications as a *Projective* Tool	Impact Elasticity between Population (P) and Water Quality $\varepsilon = \frac{\%\Delta Q_h}{\%\Delta P}$
Reflect Explicit *Linkages*	Projected Impact Elasticity of Current Population Changes on Future Ecosystem Productivity $\varepsilon = \frac{\%\Delta Q_{e;t=2010}}{\%\Delta P_{t=1990}}$
Reflect Inherent *Uncertainty*	Range of Probable Critical Levels of Water Quality Characteristic (Q_e) $\frac{\text{Projected Range } \{Q_{e;low}:Q_{e;high}\}}{\text{Projected Critical Range } \{Q^*_{e;low}:Q^*_{e;high}\}}$

An example of an indicator that could be used in a *projective* mode involves calculation of an elasticity between water quality and population. Specifically, it is the ratio of the percentage change in a water quality characteristic to the percentage change in population, based on an analysis of historical information. In this case the elasticity is a useful projective tool because the magnitude of the elasticity illustrates what would likely happen to water quality should population change. An elasticity of zero, for example, would indicate that population level does not affect water quality.

The most difficult indicator to devise is often one that *explicitly links* current human activities to future ecosystem health or productivity. The use of some form of elasticity would again be one appropriate means for conveying this information. The use of an elasticity is generally more powerful than a simple ratio because the analysis of an elasticity requires that *other factors remain unchanged.* The methods used thus require an adequately controlled experiment or, where historical data are available, enough data so that the incremental effects of just a single factor (such as population level) can be isolated. Such procedures are relatively common in economic analysis and are becoming more common in ecosystem science. "Fates and effects" and "effects monitoring" studies are now often undertaken by ecological scientists. Rigorous investigation can, in such cases, isolate the effects of selected pollutants and provide useful information to decision-makers. The moratorium on oil exploration on Georges Bank was significantly influenced by fates and effects modelling that combined laboratory-based results of research on the most sensitive life history stages of fishes, oceanographic observations, and behaviour of oil at sea to describe the link between oil spills and the well-being of commercially important fisheries; these results allowed "projections" to be made of future ecosystem productivity in the event of oil contamination. The case of sulphur emissions, acid rain, and forest productivity — discussed in the following chapter — provides additional examples of how ecosystem productivity might be tied to human activity.

Indicators reflecting *uncertainty* must be able to capture different aspects of what we do and do not know. One aspect of the uncertainty is the potential errors in the measured data, and this uncertainty can be further compounded by the actual technique that is used for projecting values. Figure 7 therefore shows that there is some projected *range* of water quality, perhaps in response to a certain change in population level. More significant, however, is describing the uncertainty inherent in what we know about the critical levels of ecosystem health. Here a range is again presented; this might be regarded as the range over which ecosystem health starts to become threatened. The range might reflect simply differences in scientific opinion, or genuine differences in observed behaviour from other research. In defining any such indicators, however, it is important to distinguish between: (a) uncertainty in the description or projection; and, (b) uncertainty in the critical level. In addition, if possible, it is important to specify what type of degradation might occur at the critical level.

In summary, Figure 7 has shown that, with a broader scope, characteristics of importance to ecosystem health — but not necessarily to immediate human health — will receive increased attention. Also, selecting indicators that are useful as projective tools will require increased use of measures that reflect stresses and responses within a single indicator. One common example of this would involve the use of "impact elasticities" that describe the behavioural response to a given stress. Such elasticities are descriptive to the extent that they can be calculated based on historical information, yet they provide decision-makers with information that has key projective applications. These projective applications are critically important in the current situation where overall ecosystem vigour and productivity is becoming a policy focus.

7 Applying the Fundamentals

Introduction

Earlier chapters suggest that the next generation of support indicators should in principle reflect five new fundamentals of indicator design. In many cases, these would form an augmentation of existing approaches to indicator reporting. In some instances, indicators and information currently reported *already* reflect some of these principles. The crux of the matter is, however, that *all* indicator design should be done in a manner that consistently reflects these fundamentals.

While the previous chapter raised some general issues on augmenting indicators, this chapter illustrates in somewhat more detail — through a specific example — how the fundamentals can be applied. It commences with a brief assessment of some commonly used reference indicators in the area of sulphur emissions. This is followed by an example of an augmentation of these indicators and some comments relating to potential areas of improvement and difficulty.

An example of the use of indicators relating to sulphur emissions has been prepared. Selection of this as an example is purely opportunistic; significant research has been undertaken in this field in support of the various acid rain reduction programmes that have been pursued in Canada and elsewhere. The OECD has prepared preliminary estimates of various indicators relating to sulphur emissions. Environment Canada's State of the Environment Report (1986) provides summaries of indicators for sulphur emissions and deposition that do reflect to varying degrees the principles of indicator design espoused here. Also, such indicators are of key relevance to the energy sector in Canada; energy sector issues are the first being addressed by the National Round Table on the Environment and the Economy (NRTEE). Finally, the 1990 Long Range Transport of Air Pollutants (LRTAP) Assessment Report, published in Canada in early 1991, provides a significant record of the state-of-the-art knowledge of sulphur emissions and their effects.

The reader is reminded, however, that the specific indicators used here are illustrative of how the fundamentals could be applied and do not represent an endorsement or suggestion that these specific indicators are the most appropriate from either a scientific or an economic perspective. More research will in many cases be necessary to determine the most appropriate indicators. The example is intended to show, however, that a *set* of indicators that reflects these five fundamentals will — taken as a whole — provide information useful to decision-makers; information in this set is not otherwise obvious from the simple "reference" indicator.

Assessing Indicators

There has been considerable international effort dedicated to the area of "criteria" for indicator design. To some degree, the five fundamentals can be thought of as "joint criteria" which can be applied to any *information set*. In general, not every indicator in any information set needs to reflect each fundamental, but the information set taken as a whole should satisfy the fundamentals as a whole. From this perspective, it is not entirely appropriate to perform an assessment of any single indicator; a single indicator is not likely to reflect all of the five fundamentals.

As a starting point, consider a set of indicators relating to sulphur emissions. As previously noted, this area has received a great deal of international attention because of efforts to reduce acid rain. With regard to indicators, the energy sector has always been a field that has provided vast amounts of historical data that have been collected using increasingly consistent conventions and techniques. The fact that most emissions come from readily identifiable point sources presents an obvious policy target. Given this proliferation of potentially useful and relevant information, it is interesting to assess some of the basic "reference indicators" that are being used.

The basic reference point for most indicators dealing with sulphur emissions is an absolute measure of emission levels:

- annual SO_x emissions (tonnes/year [t/yr]).

In addition, the OECD[6] presents, within the same information set, the following information:

- SO_x per capita (tonnes/year/person [t/yr/p])
- SO_x per dollar of output (tonnes/$ Gross Domestic Product [t/$GDP])

[6]OECD (1991), *Environmental Indicators: A Preliminary Set*, OECD: Paris.

Figure 8.
UNAUGMENTED REFERENCE INDICATORS — SULPHUR EMISSIONS

late 1980s

	Canada	U.S.A.	U.K.
SO_x emissions ('000 t/yr)	3,800	21,000	3,700
SO_x per capita (t/yr)	146	84	63
SO_x per dollar of output (t/$GDP)	9.7	4.7	7.0
SO_x per unit energy use (t/PJ)	500	310	440

The information set recommended in a background document for the NRTEE[7] also suggests inclusion of the following indicator:

- SO_x per unit energy use (tonnes/gigajoule [t/GJ])

If we suppose that these indicators — presented in a time series which shows rates of change — comprise the entire information set, we can ask "how well does this set reflect the five fundamentals?" For reference purposes, selected values of these indicators are shown in Figure 8.

First, the set does not reflect the idea that we must *broaden* the scope of our analysis to show our impacts on individual ecosystems or the condition of the ecosystem as a whole. Specifically, some measure of sulphate deposition would be more revealing in this regard.

Second, the set does not highlight *distributional* aspects except to the extent that it provides international comparisons. It should be noted, however, that the intent of these sets of indicators is often not to show any distributional aspect; Marbek (1990) asserts that a separate set of social equity indicators should be developed for this purpose, but should not be meshed with sectoral indicators such as these.

Third, *projective* applications are presented to some degree for the simple reason that ratios are presented. The ratio of "SO_x/$GDP" might be construed, for example, as an indicator that if gross output goes up by some amount then SO_x emissions might also go up by some amount in proportion to this ratio. The weakness is, however, that the simple linear ratio shows only *averages* when policy-makers are often more concerned with what will happen at the *margin*. The presentation of time series information by the OECD gets around this to some degree, but the problem then still remains of the connection between SO_x and GDP if all things are constant. It may turn out that there is absolutely no connection between them.

Fourth, the set does not inform decision-makers of the *linkages* between sulphur emissions and ecosystem productivity or health. One reason for this is that all of the measures in the set are either absolute measures, or comparative measures, of different forms of human activity. Sulphur emissions, energy use, and gross economic output are all measures of current human activity and it is not obvious to decision-makers how these will affect the health of the ecosystem and, in turn, future human health.

Finally, the information provided in the set does not reflect any dimensions of the *uncertainty* involved either in the measurement of emissions or in the confidence of what are critical levels of emissions.

Specific Augmentation of a Sample Indicator

Although the set of indicators investigated above does not by itself address all of the fundamentals, it is possible to report others such that the "augmented set" does — to a greater degree — address them. One possible augmentation is

[7]Marbek Resource Consultants (1990), *Rationale and a Preliminary Family of National Indicators for Sustainable Energy Production and Use*, NRTEE: Ottawa.

shown in Figures 9a and 9b. While there is a substantial amount of information contained in these tables, it is worth highlighting some of the features of the expanded indicator set.

The idea of a *broader scope* is captured in two ways: first, through reporting the impacts on selected ecosystems or areas that are important to human activity (such as forests); second, through describing the impacts in terms of an indicator that is more diagnostic of ecosystem stress or health. The use of sulphate deposition as an indicator does not move "all of the way" to a diagnostic indicator of ecosystem health, but it is somewhat more relevant to ecosystem stress than are simply sulphur emissions. In addition, an indicator is shown of the total area at risk to some "critical level of sulphur deposition".

Distributive information on who is affected by sulphate deposition is currently not readily available. In principle, however, it would be possible to show what proportions of the population are at risk due to high levels of sulphate deposition. In Canada, for example, economic administrative data can be coded geographically to areas as small as individual postal zones. Matching of this information with geographically-based deposition information would provide indicators that reflect distributive concerns.

Projective modes are, as noted earlier, partially reflected in the reference set of indicators. The simple linear indicator that Canada emits 500 tonnes of SO_2 for every petajoule of energy consumed is not, however, an accurate basis for projecting Canada's future emissions were energy consumption to change. A more useful indicator, as shown, would be an energy or income elasticity that describes how sulphur emissions respond to changes in energy use or income *in isolation*. At this time no such elasticities have been estimated, although statistical techniques are available to do such analyses.

An indicator that attempts to draw an *explicit linkage* between human activity and ecosystem productivity is also shown in Figure 9b. Data are available for both emission levels and forestry yield; the ratio of these two is provided as an index for discussion purposes. The information provided by the index is, however, incomplete for the same reason that the simple "SO_x/GJ" indicator described earlier is incomplete: it does not allow one to isolate the linkage. A somewhat better indicator — yet still incomplete from the perspective of making a causal connection — would be to observe changes in this index over time: an increase would mean that yields are increasing or emissions are declining. Technically, an *ideal* indicator of the linkage would again be an elasticity between forest yield and sulphur emissions. Such an indicator would represent the *isolated* effect of a change in emissions on forest yield. Ecological "fates and effects" studies have been used in some circumstances to demonstrate the existence of some of the links in the cause-effect chain.

As noted earlier, possible sources of uncertainty are (a) measurement error; (b) analytical uncertainties; and, (c) inherent uncertainties in the ecosystems based on our current scientific understanding. While in principle we might want to present all three in some format, Figure 9b does not dwell on measurement or analytical uncertainty. In the case of sulphur deposition, the inherent uncertainty in the ecosystem is probably more significant than the others. Estimates for critical levels of sulphate deposition for forests are as low as 20 kg/ha/yr and as high as 40 kg/ha/yr. For water resources, critical levels might be as low as 10 kg/ha/yr for those with low buffering capacities. The set of indicators presented in Figure 9b reflects this uncertainty. For example, a risk index is calculated that is simply a ratio of average sulphate deposition to "critical" sulphate deposition. The ranges of the indicator illustrate that in the Atlantic provinces the average deposition might — given our current understanding of criticality — have exceeded the critical levels; by contrast, in Ontario, the average deposition level has not exceeded the critical level. While it is not expected that this information will fulfil the total requirements of decision-makers, it does represent a useful composite indicator of whether further action and more detailed information is required while also communicating the potential uncertainty in the estimates.

Implications for Indicators: Areas for Improvement and Areas of Difficulty

The previous example has demonstrated some of the potential approaches to augmenting indicators. The operative policy question is whether the set of augmented indicators (such as that in Figure 9b) would be a more useful set of information than just the set of reference indicators (such as that in Figure 8).

Figure 9a.

SPECIFIC AUGMENTATION OF A SAMPLE INDICATOR — SULPHUR EMISSIONS[1]

Reference Point	General Principle or Basis	Rationale	General Examples
Reference Indicator	Standard state of environment indicator useful for descriptive purposes; focused on short-term human requirements	Sulphur emissions can provide a useful descriptive indicator of the stresses we are placing on the environment.	Common usage: tonnes SO_x/year NRTEE[2] proposed indicator: tonnes SO_x/GJ of energy used
Fundamental 1: ***Broader Scope***	ESD indicator design must acknowledge that the economy and human behaviour are part of a broader ecosystem which supports them.	We should select an indicator that will tell us how selected ecosystems are being affected by sulphur emissions.	Total sulphate deposition: tonnes SO_4/year Average sulphate deposition in important areas of ecosystem: kg SO_4/ha/year[3]
Fundamental 2: **Explicit *Distributive* Elements**	Social equity – in terms of the incidence of costs and benefits – must be an explicit component of ESD indicators.	We should select an indicator that will tell us how various income and interest groups are being affected by sulphur emissions.	Average sulphate deposition on Indian lands or marginal farm lands: kg SO_4/ha/year
Fundamental 3: **Applications as a *Projective* Tool**	ESD indicators must be useful for forward-looking applications and not just descriptive of past or current conditions.	We can rely on descriptive historical relationships that also provide information about potential future trends.	Potentially useful NRTEE indicator: tonnes SO_x/GJ of energy used Alternately, estimate impact elasticity which does not assume direct linearity: $\%\Delta SO_4/\%\Delta GDP$
Fundamental 4: **Reflect Explicit *Linkages***	Drawing connections between human economic behaviour and broader ecosystem health is a vital function of ESD indicators.	Requires information on the linkages between human caused stresses and ecosystem productivity.	Joint reporting of sulphur emissions (t SO_x/year) and growth rates of forest (m^3/year), with potential change in composite indicator of ratios: Δm^3 forest growth / t SO_x emissions
Fundamental 5: **Reflect Inherent *Uncertainty***	Unquantifiable uncertainty in ecosystem behaviour and response requires that ESD indicators must explicitly communicate such uncertainty to decision-makers.	Requires us to express both the potential ranges in current measurement as well as the potential levels of criticality in ecosystem modification.	Joint reporting of range of actual deposition levels (t SO_4/ha/yr) with potential range of levels critical to ecosystem health (t SO_4/ha/yr). Composite indicator of range of attained percentage.

[1]Prepared by H.J. Ruitenbeek for the Canadian Environmental Advisory Council, 1991. The indicators used here are illustrative of how the fundamentals could be applied and do not represent an endorsement or suggestion that these specific indicators are the most appropriate from either a scientific or an economic perspective. More research will in many cases be necessary to determine the most appropriate indicators.

[2]From discussion paper by Marbek (1990) circulated by National Round Table on the Environment and the Economy (NRTEE).

[3]Environment Canada's State of the Environment Report (1986), for example, shows forest areas affected by different levels of sulphate deposition.

Figure 9b.
Specific Augmentation of a Sample Indicator — Sulphur Emissions[1]

Reference Point	Specific Examples of Data			Comments on Source and Derivation
Reference Indicator	Country:	SO_2 ('000 t/year)	t SO_2/PJ	Emission estimates are based on data for the mid-1980s as summarized in *WRI World Resources 1990-1991*. Intensity estimates are derived from these and IEA energy consumption data. [Note that 1 PJ = 1,000,000 GJ.]
	Canada	3,760	500	
	U.S.A.	21,100	310	
	China	12,920	550	
	U.K.	3,750	440	
Broader Scope	Area in Eastern Canada:	kg SO_4/ha/yr	Area at Risk	Estimates are based on deposition in early 1980s and are calculated from data provided in Environment Canada SOE Report. Area at risk represents proportion subject to deposition in excess of 20 kg/ha/year of sulphate deposition. For water resources, areas with very high buffering capacities are excluded from areas at risk, even if deposition exceeds the 20 kg/ha/year level; areas with low buffering capacities are regarded at risk if deposition exceeds 10 kg/ha/year.
	Wheat Growing Areas	42.9	99.6%	
	Corn Growing Areas	43.6	100.0%	
	Forests	22.7	41.2%	
	Water	23.5	46.8%	
Explicit *Distributive* Elements	Economic Interest Group:	kg SO_4/ha/yr	Population at Risk	Calculation of these indicators would be based on similar information to that above, except that it also requires an analysis of spatially organized economic data. All data are available in Canada, yet require some supplementary analysis before indicators can be represented.
	Populations on Native Lands	not available	not available	
	Farms with income less than:			
	$500,000/year income	not available	not available	
	$100,000/year income	not available	not available	
Applications as a *Projective* Tool	Simple linear indicator: Canada = 500 t SO_2/PJ Energy Consumed Non-linear indicators based on cross-section or historical time-series analysis: Energy Elasticity = $\frac{\%\Delta SO_2 \text{ Emissions}}{\%\Delta \text{ Energy Consumption}}$ = not available Income Elasticity = $\frac{\%\Delta SO_2 \text{ Emissions}}{\%\Delta GDP}$ = not available			These indicators are useful to projective applications as there is an implicit behavioural linkage between key human activities. Such information provides a basis for both further intuitive and formal analysis of what might happen if certain things occur in the economy (such as income going up). The simple linear indicator (based here on the reference indicator above) is often used as an index of intensity; and is a simple example of an indicator with potential projective applications. A more rigourous approach is to use non-linear impact indicators ("holding other factors constant") that can still be expressed as a single "impact elasticity".
Reflect Explicit *Linkages*	Forested Regions in Eastern Canada:	Ontario	Quebec / Atlantic	Annual emissions based on 1990 estimates. Annual yields based on Environment Canada SOE Report estimate of yield from forests in area of sulphate deposition greater than 10 kg/ha/yr. Index calculated as simple ratio.
	Annual Emissions of SO_x (million t)	1.0	0.6 / 0.4	
	Forestry Annual Yield (million m^3)	44.6	81.5 / 24.2	
	Index of Yield/Emissions (Base)	45	135 / 60	
	Index (Next Period)		not available	
	Δ Index		not available	
Reflect Inherent *Uncertainty*	For forests at risk in:	Ontario	Quebec / Atlantic	Estimates are based on deposition in early 1980s and are calculated from data provided in Environment Canada SOE Report. Critical levels reflect best available scientific estimates of maximum deposition that areas could withstand before ecosystem vigour and productivity declines. Risk Index is simple ratio of actual levels and critical levels.
	Average sulphate deposition (kg/ha/yr):	19.7	21.0 / 27.6	
	Critical sulphate deposition (kg/ha/yr):	20–40	20–40 / 20–40	
	Risk Index (%)	49–98	52–105 / 69–138	

[1]Prepared by H.J. Ruitenbeek for the Canadian Environmental Advisory Council, 1991. The indicators used here are illustrative of how the fundamentals could be applied and do not represent an endorsement or suggestion that these specific indicators are the most appropriate from either a scientific or an economic perspective. More research will in many cases be necessary to determine the most appropriate indicators.

The analytical and scientific challenge of providing such augmented information is not insurmountable. As discussed, it is quite feasible to incorporate a broader scope, distributive elements, and projective abilities in the information we present. It is more of a challenge to specify critical values or constraints to activities, although even this is possible if such estimates explicitly reflect their uncertainty. Probably the most difficult challenge will be to provide explicit linkages between human activities and ecosystem productivity. Even this, however, is becoming increasingly feasible in the wake of ecological "effects" research on particularly important or sensitive areas.

But it must be recognized that the basic approach of "augmentation" has both advantages and disadvantages. The primary advantage, and the reason it is being used here, is that it allows analysts and decision-makers to formulate indicators that are natural extensions of indicators with which they are already somewhat familiar. This facilitates analysis, presentation, understanding, and eventual adoption of the expanded information set in the decision process.

There are also, however, two potentially serious disadvantages to the augmentation process. First, it assumes that the set of starting point reference indicators we are using is already relatively complete. By contrast, it is conceivable that there are indicators that are potentially important but which would not naturally fall out of any particular augmentation procedure. One example of such an indicator, suggested during the indicator workshop, is the net primary product of terrestrial photosynthesis used or preempted by human activity; this was estimated to be about 40%. This measure may be taken as a rough index of how big the human sub-system is relative to the total system. It is unlikely that such information would be arrived at through a simple augmentation of existing reference points. The second disadvantage to augmenting a reference indicator is that any weakness in the scientific basis for the reference indicator may not necessarily be eliminated in the augmentation process. The example of sulphur emissions and sulphate deposition, described above, illustrates this point. It is believed, however, that neither of these disadvantages outweigh the advantages of using an approach which augments existing indicators. The first problem — incompleteness of the information set — simply requires us to be open to other types of information. The second problem — persistence of a potentially weak scientific basis — underlines the need to include both explicit linkages and measures of uncertainty within the information set.

8 Next Steps

Introduction

To reiterate a statement made by one of the indicator workshop participants, let us propose that enough is known about ecosystem dynamics for economists to get started on making it an intrinsic element of economic policy, and, for ecologists to start making the conduct of human activity an intrinsic element of ecosystem science. In response to this challenge, it is appropriate that the "five new fundamentals" proposed in this paper become part of any accepted framework for ESD indicator design.

While it is expected that most readers will be able to identify specific steps and actions that are appropriate within their own discipline or sphere of influence, this chapter identifies some key areas that are believed to be particularly important to assist in future indicator design. Appropriately, some priority work areas are identified, and a generic three-part strategy is suggested for augmenting existing information sets.

Some Priority Work Areas

It is acknowledged that there still remains substantial disagreement over many of the technical issues in indicator design. Rather than seeking to resolve this disagreement before indicators are put forward, however, it is clear that the very generation, interpretation, and continued refinement of indicators will eventually contribute to the resolution of these disagreements. It is equally clear that new disagreements will emerge as our information set becomes richer and our knowledge improves. Nonetheless, some immediate work is in order to support the indicator development efforts.

The work priorities can be summarized as follows:

a) within the economics discipline, start to code information geographically such that it can be linked easily to geographically-based information from the natural sciences. This is likely to require a fairly high degree of resolution if, for example, distributive impacts of ecological problems are to be measured. The alternative to this "geo-coding" procedure is to code all of the environmental data using economic conventions. As the end goal is to present only *selected* environmental information for selected economic groups, it would not be efficient to do this for all environmental data.

b) within the economics discipline, start to build "flexible constraints" into analytical procedures which reflect potential critical limits of the broader ecosystem. The existence of "constraints" reflects the idea that we live within the broader ecosystem but, analytically, they must be flexible such that projective analyses can reflect some uncertainty in their levels.

c) within the economics discipline, commence historical analyses of linkages between human activities and potentially relevant indicators of ecosystem health. While this might appear at first glance to be a job for the natural sciences, economists have a certain comparative advantage in this area because the analysis will involve applying analytical techniques commonly used within the economics discipline to time series or cross-sections of economic and "ecological" information. One potential avenue of research is to follow up on the idea that humans are themselves potential "indicator species" of ecosystem health. Human health characteristics — for which historical data can be quite good — might therefore provide some links to broader ecosystem health.

d) within the natural sciences, develop ranges of potential critical limits for key ecosystems. The ranges can and should explicitly reflect the uncertainty in ecosystem behaviour and scientific understanding of that behaviour. These critical limits should be developed in consultation with the economics discipline to ensure that the information is (i) understood and (ii) something that can be accommodated within analytical structures typically used in policy analysis. For example, consider three indicators such as "sulphur emissions", "sulphate deposition on water areas", and "trophic levels". The first is the easiest to accommodate within economic models because it is a direct result of human activity, but it is a poor indicator of ecosystem health. The latter is, conversely, probably the best indicator of ecosystem health, but it is not readily built into economic models. In this case, sulphate deposition — or some variant of it — appears to be a tractable compromise.

e) within the natural sciences, select and report indicators that provide policy-makers with an idea of how "healthy" various ecosystems are. It is recognized that there will be disagreement within the discipline over what the appropriate measures are, but at this stage the goal of the exercise must still be to familiarize policy analysts and decision-makers with this *type* of information. The use of indicators relating to keystone species, charismatic species, or indicator species would provide a good start to communicating this information, but explanations of *why* these particular species are relevant to ecosystem health is an important component of the process.

f) within the natural sciences, improve the scientific understanding of ecosystem dynamics with a view to describing the linkages between ecosystem stresses that might be caused by human activity, and overall ecosystem health. In particular, this work could be oriented towards eventually being able to specify some appropriate "early warning signs" for ecosystem distress.

Through all of these activities, it is clear that continued interdisciplinary work is important. Realistically, however, each discipline will continue to have comparative advantages in some areas. Further, the magnitude of the research programme that needs to be undertaken dictates that economists will continue to do some types of work while ecosystem scientists will continue to do other types of work.

Implementing the Fundamentals: A Three Part Strategy

While the preceding section described some of the supportive longer-term research and analytical work which would be necessary to develop better ESD indicators, an immediate priority must also be to commence programmes which ensure that the fundamentals are, to whatever degree possible, reflected in the indicators that decision-makers will be using. The precise manner in which *programmes* of indicator design are implemented will differ considerably among institutions or organizations. In general, however, any implementation strategy will consist of three parallel initiatives, as shown in Figure 10.

First, a basic programme which supports the development of "bottom-line" descriptive indicators will remain as one of the three focal points. In general, this can continue to build on sectoral work that is currently being conducted within Canada and other countries. There will, however, be some reorientation required of programmes that currently regard "social equity" indicators separately in their own "sector". The general position taken in this paper is that

Figure 10.
A Three Part Implementation Strategy

I: Basic Programme

Continue development of descriptive "bottom-line" indicators.

II: Extension Programme

Augment descriptive indicators with enhanced indicators that:

- show policy and behaviour impacts and linkages;
- reflect distributional elements; and,
- reflect uncertainty.

III: Complementary Programme

Augment technical work to define indicators that project how close we are or will be to ecosystem "constraints".

Select and increase reporting of ecosystem health diagnostic indicators.

attempts should be made to integrate the social equity dimension into all sectoral indicators.

Second, an "extension" programme will be required within each sectoral effort to develop indicators that show: the impacts and linkages involved with economic behaviour; the distribution of costs and benefits in a manner that reflects social equity concerns; and, some dimension of uncertainty. The uncertainty dimension can be as simple as expressing potential "error ranges" with the reporting of indicators, or as complex as comparing projected values in relation to ranges of critical values.

The third "complementary" programme involves increased attention by the natural sciences to developing physical indicators that can be used as points of reference in the behavioural analysis undertaken within the social sciences. As a first — but not insignificant or simple — step, this will require focusing on potential physical constraints to economic activities. A second — more complex — step will be to increase the reporting of various types of diagnostic indicators for ecosystems so that policy analysts and decision-makers will become increasingly familiar with indicators of ecosystem health. As noted earlier, one means of promoting such a complementary programme in the natural sciences is to support ecosystem research at a substantial level.

Closing Remarks

The focus of this paper has been to discuss indicator design in a context that is sensitive ultimately to the needs of policy-makers. It is well recognized, however, that policy-makers are not the only users of this information. Corporations, scientists, and the general public all will contribute to the generation and interpretation of the information used by these policy-makers. But to the policy-makers we propose that information which reflects the five fundamentals enumerated in this paper will provide them with a better information set than will simple descriptive indicators.

Decisions should be based on information that reflects a broader scope, distributional concerns, projective elements, the explicit linkages between human activity and ecosystem health, and the inherent uncertainty in all of these. Decisions so made will lead to policy initiatives that will rise to and meet the challenge of formulating programmes consistent with ecologically sustainable development.

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